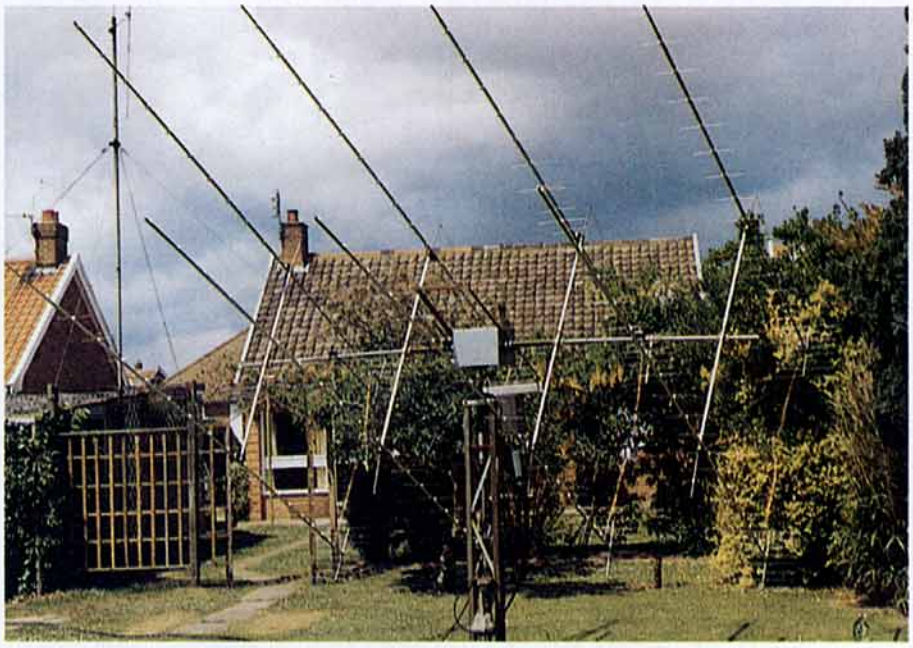
RADCOM TECHNICAL FEATURE

An Introduction to MOONBOUNCE

144MHz EME by Ray Soifer, W2RS

INTEREST AMONGST UK amateurs in 144MHz earth-moon-earth (EME) communication has grown rapidly since the maximum output power available to UK CW operators was increased from 100 to 400W (from 20 to 26dBW), from 5 April 1991. Much new activity has also come through the efforts of Graham Daubney, G8MBI, and Mark Turner, G4PCS, whose outstanding results with their jointly-maintained station have inspired many to try EME for themselves. These have been described in *RadCom's* monthly *VHF/UHF News* and elsewhere. I have worked G8MBI (and 24 other stations) myself via the lunar route using no more than 150W and a single 19-ele Yagi. In January 1992, CO2KK worked KB8RQ using just 25W and two 5-ele Yagis! If you have reasonably good CW operating skills and your present 2m station is capable of meteor scatter, with the proper techniques it is probably also capable of EME.



Doug Mallett's, G3HUL, home constructed 430MHz EME antenna system utilises 8x28-ele Yagis.

LUNAR PROPAGATION

LET US CONSIDER how you, as the owner of a good, but by no means exceptional, 2m CW station, might join in [1]. In this discussion, we will assume that your present station includes a good quality GaAsFET preamplifier, 100W output at the antenna and a single Yagi, such as a 14-ele Parabeam or 16-ele F9FT, having forward gain in the range of approximately 14.8dBi [2]. Does this sound familiar? The effective isotropic radiated power (EIRP) of such a station would be about 34.8dBW (3.0kW).

Now let us consider the propagation path from Earth to the moon and back again. When the moon is at perigee, it is approximately 221,000 miles (356,000km) away. It is, of course, roughly spherical (very roughly) with a diameter of about 2,160 miles (3,480km), subtending about 0.5° of arc as seen from the Earth, but with a typical radio reflectivity at this frequency of only about six percent. Under these optimal conditions, the path loss at 144MHz is approximately 251.5dB.

This approximates to the attenuation if you were trying to receive a signal from a space probe located at the orbit of the planet Jupiter some 400 million miles distant. When the moon is at apogee (253,000 miles or 407,000 km), the path loss is 2dB greater, or about 253.5dB [3].

CALCULATING THE S/N RATIO

Optimal receiving conditions occur when the moon appears against the quietest point in the cosmic noise map - the so called 'cold sky' level. That does not occur very often but when it does, the sky noise heard by your receiver at 144MHz measures approximately 165K. If we assume a receiver noise temperature of 80K, a figure typical of a station with good GaAsFET preamp, low-loss switching circuits and a high-quality converter, the combined noise level in your receiver (in a bandwidth of 100Hz) would be about -154.7dBm with the antenna aimed at 'cold sky'. So, under these ideal conditions, how close would you come to hearing your own signal reflected from the moon?

If (S/N) = Pt + Gt + Gr - Lp - Pn,

where

Pt = transmitted power (in this case 100W or +50dBm)

Gt = transmitting antenna gain (14.8dBi)

Gr = receiving antenna gain (the same as Gt)

Lp = path loss (251.5dB)

Pn = receiving noise power (-154.7dBm)

I'm afraid the answer isn't very encouraging - according to the above equation, your received signal will be approximately 17.2dB below the noise level. But wait, there's more!

SYSTEM DEGRADATION (DGRD)

To begin with, the reality is even worse than we have calculated. How often, after all, is the moon at perigee and at the point of lowest sky noise at the same time? Hardly ever. Some years ago, Derwin King, W5LUU, came up with a convenient definition of 'system degradation' to take into account the moon's actual position relative to the earth and the background of cosmic noise; according to W5LUU's convention, system degradation (often referred to as DGRD in lunar tracking software) is the difference between the actual S/N ratio and the one that would prevail at perigee and a 'cold sky', assuming a receiver noise temperature of 80K as we have done. Although occasionally near zero and sometimes 10dB or more, DGRD typically varies between about 1 and 4dB most of the time; the mean value which I have encountered in my EME contacts so far is 2.5dB. DGRD, as we and W5LUU have defined it, subtracts directly from the S/N ratio, so to adjust our 'optimal' predictions for more realistic conditions, we must increase the signal deficit to 19.7dB for DGRD of 2.5dB. Not a very good start, is it?

GROUND STATION REQUIREMENTS

One of the wonderful things about EME is that you really do not have to be able to hear your own reflected signal in order to make two-way

PHOTOGRAPHS: Although 144MHz antenna photographs were not supplied for this feature, we felt that readers may be interested in EME arrays for other bands.

contacts. If the station at the other end has a larger antenna and more power than you have, all that really matters (most of the time) is that he hears you. After all, I hope you already know what you're sending!

So then, what kind of receiving station would it take to hear your signal via the moon? Referring to the signal deficit of 19.7 dB which we calculated earlier for DGRD = 2.5dB, a receiving array large enough to hear your station (S/N = 0 dB in a bandwidth of 100Hz) would have to have forward gain of 34.5dBi. This sounds like a lot (a power factor of 1,600 or about 32dB over half-wave dipole) but it is actually only 1.2dB more than the 48-Yagi array presently in use at W5UN in Manvel, Texas. Can Dave Blaschke's, W5UN, celebrated ears pick out a signal 1.2dB below the noise in a 100Hz bandwidth? Perhaps, but if DGRD is 1.3dB (a value that frequently occurs in practice) instead of 2.5dB, the S/N deficit for W5UN would be eliminated entirely. Under conditions which are better than average but not at all improbable, our figures show that W5UN might well be able to hear your station 'as is'.

GROUND-REFLECTION GAIN

NOW FOR SOME INGENUITY which should help to improve your performance. The typical level of sky noise encountered at 144MHz (for my own EME contacts, an average of 291K) is not far removed from the 290K 'black body' radiation picked up from the earth itself when the antenna is pointed at the horizon rather than up into the sky, ie at lunar elevation angles of about 12° or less. Pointing the antenna at the horizon generally results in enhancement of the transmitted signal through ground-reflection gain of 3 - 5dB; the enhancement would be 6dB were the Earth a perfect reflector. In view of the actual sky noise typically prevailing at 2m, the price paid for this in receiving capability is often little to nonexistent, particularly for those living in quiet locations or operating at times when man-made noise is not likely to be prevalent [4]. Another feature of utilizing ground-reflection gain is that, since the antenna is required to be aimed at the horizon, the need for an elevation rotor may be eliminated as long as you are willing to restrict your EME operation to those times when the moon is less than approximately 12° above the horizon!

POSSIBLE RESULTS

UTILIZING THIS GROUND-REFLECTION effect, I have made several EME contacts with W5UN at 144MHz using only 50W output to a 3.2λ, 19-ele Cushcraft Yagi, which produced an EIRP of only 32.1dBW. This is approximately 2.7dB less than the 100W station we postulated earlier. Gary Kohtala, operating as HL9TG with the US Army in Korea, put together a simple station running 80W to a single 4.2λ Yagi (35.4dBW EIRP, about the same as our assumed station) and worked not only W5UN but also KB8RQ, VE7BQH and N5BLZ. Can a 'typical' 2m CW station work EME? With ground-reflection gain, most certainly yes!

RESULTS AT W2RS

So far, my own QSO count on 144MHz EME, with 150W and the single 3.2λ Yagi (37dBW), is 66 with 25 different stations, including not only 'superstations' such as W5UN with 48 18-ele Yagis, but seven stations in the four-yagi class, three with six, and seven (including G8MBI) with eight Yagis or the equivalent. **Table 1** lists each of the stations I have worked along with the arrays which they used to work me.

GOING ONE BETTER (OR MORE)

If you increase the power of your station (as we have assumed it) from 100W to 200W, or add a second Yagi, you'll have more EIRP than I do! A 'serious' EME station which uses the new UK CW power limit of 26dBW to four 4.8λ Yagis (eg K6MYC's popular 2m-5λ design) would produce approximately 48.2dBW

David Jones', GW3XYW, dish is 22 feet (6.7 metres) in diameter. This impressive array provides effective earth-moon-earth (EME) operation on the 23cm (1.3GHz) band.

W2RS – 144MHz EME

Stations Worked and their Antennas Employed (1)

Station	Array (2)	Estimated gain (dBi)	Notes
W5UN	48x4.8λ	33.3	Random QSO, worked with 50W CW
W5UN	48x4.7λ	32.5	Random QSO, worked with 150W SSB and 50W CW
W5UN	32x4.7λ	30.4	Random QSO, worked with 130W CW
KB8RQ	24x5.7λ	30.0	Random QSO, mutual horizon gain
SM5FRH	24x5.2λ	29.7	
KB8RQ	24x4.8λ	29.5	Random QSO
KB8RQ	32x3.2λ	29.3	Worked with 130W CW
N5BLZ	16x5.2λ	28.0	
KB8RQ	16x4.8λ	27.8	
W4ZD	16x4.8λ	27.8	Mutual horizon gain
WB5LBT	16x4.8λ	27.8	
K1WHS	24x2.2λ	27.0	Mutual horizon gain
N5BLZ	12x4.7λ	26.7	
SM7BAE	16x3.1λ	26.3	Worked with 130W CW
K2GAL	8x5.9λ	26.1	Mutual horizon gain
DL8DAT	16x2.8λ	26.0	
VE7BQH	336ele Coll	25.7	
AF9Y	6x6.2λ	25.4	
HB9CRQ	8x4.8λ	25.0	
K9MRI	8x4.8λ	25.0	
I2FAK	8x4.7λ	25.0	
VE7BQH	224ele Coll	24.2	Worked with 130W CW
G8MBI	224ele Coll	24.2	
OK1MS	8x3.6λ	24.1	
SM2CEW	6x4.2λ	23.6	Mutual horizon gain
K2GAL	4x6.2λ	23.3	Mutual horizon gain
K3HZO	6x3.2λ	23.1	Mutual horizon gain
N1BUG	24x4ele Quad	22.8	Mutual horizon gain
AA4FQ	4x5.1λ	22.3	Ionospheric scintiliation
W7VXW	4x4.8λ	22.2	Strong libration peaks
KI3W	4x4.2λ	21.9	Mutual horizon gain
WB2JHG	8x1.5λ	21.6	Mutual horizon gain
WB2OYC	4x2.2λ	19.7	Mutual horizon gain

Mean Conditions Prevailing:

Sky noise	291K
Path loss over perigee	0.8dB
System degradation (3)	2.5dB

Notes:

(1) Except when noted, W2RS output power was 150W CW to a single 3.2λ Yagi. 150W CW to a single 3.2λ Yagi.

(2) Except as noted, all antenna systems are multi-Yagi arrays where nλ is the length of each Yagi in wavelengths.

(3) System degradation, as defined by W5LUU, is the overall S/N degradation with respect to ideal conditions (perigee and sky noise of 165K) assuming a receiving system noise temperature of 80K.

Table 1.

First 90 Seconds	Final 30 Seconds
G8MBI DE W2RS G8MBI DE W2RS G8MBI DE W2RS	G8MBI DE W2RS K
W2RS DE G8MBI W2RS DE G8MBI W2RS DE G8MBI	W2RS DE G8MBI K
G8MBI DE W2RS G8MBI DE W2RS G8MBI DE W2RS	O O O O O O O K
RO RO RO RO RO RO RO RO RO RO RO RO RO RO	DE G8MBI K
R R R R R R R R R R R R R R R R R R R R	DE W2RS K
73 73 73 73 73 73 73 73 73 73 73 73 73 73	DE G8MBI AR

Table 2 (see page 68 - Operational Procedures).

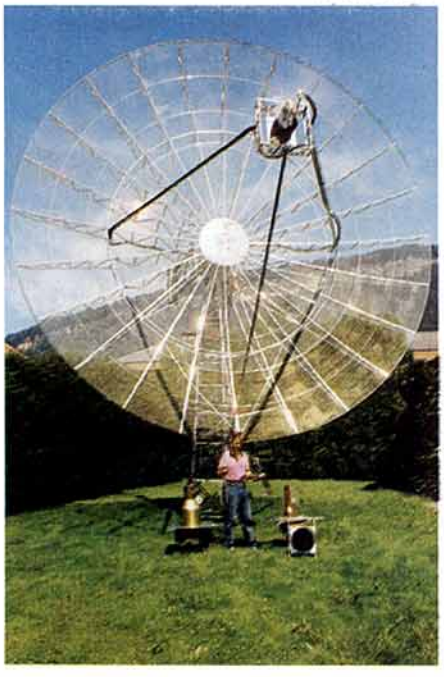
EIRP; 2m EME stations with EIRP in this range, eg, OZ1HNE, EA3DXU and WD5AGO, have worked more than 100 different stations 'off the moon'. Many stations have now earned Worked All Continents via 144MHz EME, and W5UN has already received the first 144MHz DXCC award with the several others having 2m country totals that are nearing the century mark.

For those with EIRP of 40dBW or more, the greatly increased flexibility to be gained by adding an elevation rotor would be well worth while. Full az-el control also offers a reduction in man made noise and the ability, when receiving to take to take advantage of times when lunar sky noise is well below 290K. On the other hand ground-reflection gain generally disappears at antenna elevation angles above 12° or so, and for the low-power station, the 3-5 dB of additional signal strength it affords often means the difference between success and failure.

MUTUAL HORIZON GAIN

WE'RE NOT QUITE THROUGH WITH the ingenuity which makes 144MHz such an interesting band for EME. Depending upon the position of the moon relative to the two stations involved, schedule times sometimes can be chosen so that ground-reflection gain is available at both stations simultaneously. Instead of 5dB, the total enhancement from this source can thus approach 10dB. This 'mutual horizon gain' effect was used to accomplish all but two of my contacts with the four-Yagi stations, as well as one with SM2CEW, a six-Yagi station in Lulea, Sweden, proving that mutual horizon gain does not always require both stations to be in close geographic proximity [5]. Because both stations in such a contact will be picking up 'black body' radiation from the Earth, it is often advantageous in such cases to schedule times when the moon will be at or close to perigee to minimize path loss, even though the predicted sky noise may be at or even somewhat above 290K.

PHOTOGRAPH GW3XYW



An 8m diam. dish is used by OE9ERC on 2.3GHz.

LIBRATION ENHANCEMENT

THE MOON'S LIBRATION (wobbling) in orbit gives rise to a quasi-random fading effect on reflected signals. Given the statistical fading distribution, it has been calculated that this libration fading can add 4.5dB to reflected signal levels 10% of the time and 7.0dB 1% of the time. The maximum fading enhancement is in the neighbourhood of 10dB, which would be equivalent to momentarily increasing the moon's reflection coefficient from 6% to 60% [6]. The duration of these signal enhancements is inversely proportional to frequency. At 70cm they typically last less than one second, rendering them relatively useless for practical communication at the narrow bandwidth commonly employed in amateur EME. However, at 2m, libration peaks often last as long as 3-4 seconds, making them extremely useful when CW sending speeds of 15-20 WPM are employed. For example, at 18WPM, my call sign takes less than three seconds to send.

HEARING MY OWN LUNAR ECHOES

With my output of 37dBW EIRP, the theoretical S/N ratio for hearing my own lunar echoes (excluding ground-reflection gain and assuming a noise level of 290K) is approximately –17.4dB; I went nearly five years without once hearing my own signal coming back from the moon. However, making use of mutual horizon gain (when listening for one's own echoes, the horizon gain is always mutual!) and libration enhancement at times of lunar perigee, this deficit has been overcome for brief bursts of signal (less than 1 sec) captured on tape. The preceding discussion illustrates how this was done.

When listening for one's own lunar echoes, it is important to realize that the distance from the Earth to the moon and back again results in significant time delay, which ranges from 2.4 sec at perigee to 2.7 sec at apogee.

OTHER UNUSUAL EFFECTS OF EME

DOPPLER EFFECTS

Although the moon's motion relative to the Earth is relatively slow, EME signals experience significant Doppler shift; the main contributor to this is actually the Earth's rotation on it's axis. For the maximum case, ie a station on the equator listening for it's own echoes when the moon is due east at moonrise or due west at moonset, the Doppler shift would be about 460Hz at 144MHz. The return signal would appear higher in frequency than nominal by that amount with the moon to the west. The actual Doppler shift encountered in practice is generally less, depending upon the actual geometry involved. Typical values at temperate latitudes, when the moon is near the horizon at one of the two stations involved, are 200-300 Hz.

FARADAY ROTATION

As with man-made satellites, Faraday effects are commonly encountered in EME as well. As virtually all Yagi antennas utilised in EME work are horizontally polarised, Faraday can be a major impediment to successful communication, often necessitating multiple schedule tries before a completed contact can result. Linear polarity is used in 2m EME rather than circular mainly because forward gain is at such a premium relative to antenna size and weight; in addition, ground-reflection gain is maximised when horizontal polarity is employed.

A few 2m EME operators, notably Lionel Edwards, VE7BQH, have experimented with Z-axis rotation in an attempt to match the polarity of the incoming wave. Results achieved have been very successful; however, not many stations have taken this approach because of the mechanical complexity involved. Using a Z-axis rotatable collinear array, VE7BQH has made a study of the Faraday effects, concluding that truly linear downlink polarity occurred only about 15% of the time. About 60% of the time, multipath effects (combined with frequency and phase distortion) resulted in signals appearing at multiple polarity points at the same time. 25% of the time, the incoming signal exhibited no discrete polarity characteristics at all, but appeared approximately equal in strength regardless of the Z-axis position of his antenna! [7]

LUNAR TRACKING AIDS

AS WITH MAN MADE SATELLITES, it is necessary to track the moon in order to point antennas properly; the large arrays often employed in EME work, and the weak signals, require more precise tracking than is often the case with artificial satellites. Man has been tracking the moon for thousands of years, certainly long before the invention of the computer. In the early days of EME, the 1960s and 1970s, amateurs often used nautical almanacs to aim their antennas. Even today telescopes and optical boresights are commonly used, albeit more often in Arizona than in Britain. However, just as with Oscars, the use of a computer makes EME far easier and more enjoyable.

SATELLITE-TRACKING SOFTWARE

Many of the modern satellite-tracking programs, such as Satscan and Instant Track, will track the moon with accuracy sufficient for a single Yagi station. However, they lack features important for arranging EME schedules such as a built-in sky noise map for calculating system degradation (DGRD). For all but the most casual applications, I strongly advise the use of a good special-purpose EME program.

SPECIAL-PURPOSE EME SOFTWARE

For those with IBM PC-compatible hardware, readily available alternatives include a public-domain program by VK3UM that is in common circulation as well as a newer, more complete program called Tracker by WA1JXN; the latter is also available for the Amstrad PCW series. Information on obtaining either of these programs in the UK appeared in G3FPK's fine column in the May 1991 issue of *RadCom* [8]. By far the best of the current EME programs which I have seen, in my judgement, is W5UN's own Skymoon [9]. Hardware requirements for this are an EGA or VGA display plus a hard disk. In addition to the features of the other programs mentioned, Skymoon incorporates the entire

current *144MHz EME Directory* of active stations so that mutual windows may be determined easily.

OTHER USEFUL INFORMATION SOURCES

The Directory itself, containing well over one thousand detailed entries, is updated continuously and may be obtained from Bev Cavender, W4ZD [10].

Also strongly recommended are the monthly *2-Meter EME News* published by K0IFL [11] (successor to the now defunct *2 Meter EME Bulletin*) and the UK newsletter, *2M Direct*, edited by G4PCS [12].

EME OPERATION

FINDING STATIONS TO WORK

Now that you have assembled a station and know where to find the moon, what do you do? Most current EME activity takes place by prearranged schedule. Virtually all the operators mentioned in the newsletters (as well as the larger stations listed in Table 1) would be happy to arrange such a schedule with you. EME operators, after all, are in a friendly competition to see how many stations they can work.

As a 'new boy' (or girl), you'll soon find yourself popular indeed! During almost any weekend with favourable EME conditions, you are likely to find several of the larger stations calling CQ on their customary calling frequencies near the low end of the 2m band. W5UN, for example, may generally be found on 144.008MHz while KB8RQ is usually on 144.016. The antennas listed in Table 1, by the way, are those in use at the time I worked the station - many have since installed larger arrays.

There are approximately three times as many active EME stations on 2m as on 70cm, no doubt because of the wide availability of suitable equipment; W5UN has worked over 1,400 of them. Among those currently active are 24- and 16-Yagi 'super stations' such as KB8RQ, SM5FRH, DL8DAT and N5BLZ with 28-30dBi forward gain, which have no difficulty working those with 100-150W and a single Yagi.

The most common way of arranging schedules is through the 2m EME Net which meets Saturdays and Sundays on 14.345MHz. The net control stations normally listen for check-ins from Europe after collecting schedule proposals from North America; this generally takes place around 1900 or 2000GMT. This frequency is also used as a meeting place for EME and VHF-oriented operators at times when the nets are not in session.

CW V SSB

OWING TO THE WEAK SIGNALS involved, more than 99% of all current Earth-Moon-Earth activity utilises CW rather than SSB. The latter is sometimes used by the larger stations and 144.155MHz is the usual SSB gathering place. I have had several SSB contacts with W5UN but have not been successful using this mode with other stations.

OPERATIONAL PROCEDURES

On-the-air EME procedure differs somewhat between 2m and 70cm. At 2m, schedules are typically half an hour in length (although I normally run mine for one hour) and are divided into two-minute segments (not 2.5 minutes as at 70cm). There is nothing sacred, of course, about two-minute segments. I have found, for example, that mutual horizon gain schedules work best if each station transmits for one minute in turn (owing to the extremely rapid Faraday rotation often encountered when the moon is near the horizon at both stations), and W5UN prefers one minute segments for his random CQ activity. In the absence of agreement to the contrary, however, two-minute segments are normally assumed.

Also by convention, the easternmost station transmits during the first segment of each hour, then the third, etc. At 2m, the T-M-O-5 system of signal reports employed at 70cm has fallen into disuse. In internationally-accepted 2m EME procedure, the only signal report sent is the letter 'O', and that only after both call signs have been received satisfactorily. Receipt of the 'O' report is acknowledged with the letter 'R' for 'roger'. A typical 2m EME QSO would go something like **Table 2**, segment by segment:

In this example, I began sending 'O' reports in the final 30 seconds of each segment as I heard Graham's and my call signs from him. The 'RO' from G8MBI signifies that he has heard my 'O' as well as both call signs from me and is giving me a report of 'O' in return. Had he heard my 'O', but just the call signs, then he would send call signs in the first 90 seconds and 'O' in the final 30 seconds, until he hears my 'O' or I hear his.

Assuming that he hears my 'O' first, then he would switch to the 'RO' sequence indicated. When I hear his 'RO', I switch to send 'rogers' ('R'). The 2m EME contact is considered to be complete at the moment G8MBI hears my 'R' since I would not have been sending that had I not heard his 'RO'. Thus, both stations have received call signs, reports and rogers. The sending of '73' is a nice touch but is actually superfluous.

The 8x21-ele F9FT antenna used by SK6AB.

IT'S YOUR TURN

I HOPE YOU WILL CONSIDER giving 2m EME a try. After all, the moon (sometimes referred to as 'Oscar Zero' by satellite enthusiasts) is one satellite that is always available for use, is incapable of being overloaded and actually encourages high levels of EIRP. As I have hopefully demonstrated, however, high EIRP is not at all necessary if the proper techniques are employed. As Pat Gowen, G3IOR, has often remarked, EME is the ultimate operating challenge. If you haven't yet tried it, the moon awaits!

REFERENCES

[1] For similar calculations involving Oscar-type stations at 2m and 70cm, see my paper, 'Oscar Zero: An introduction to EME for the Satellite Operator', in the *Proceedings of the sixth AMSAT-UK (University of Surrey) Colloquium (1991)*, from which this article has been revised and adapted. The Proceedings are available from AMSAT-UK, 94 Herongate Rd, Wanstead Park, London E12 5EQ.

[2] Antenna gain estimates for this article were taken from LM Edwards, VE7BQH, '2 Meter EME Antennas', *2-Meter EME News*, Issue 8, May 1990.

[3] For a further discussion of the technical parameters of EME, see *VHF/UHF Manual*, 4th edition, G R Jessop, G6JP, RSGB, 1983, pp 10-16 et seq.

[4] See also my articles in *QST*, 'QRP EME on 144MHz', Feb 1989, pp 28-32, and 'More QRP EME on 144MHz', Oct 1990, pp. 36-38.

[5] Further details on this effect are given in my paper, 'Mutual Ground Gain', *2-Meter EME News*, Issue No 17, Feb 1991.

[6] C Neie, DL7QY, 'Libration Fading', *2 Meter EME Bulletin*, Oct 3, 1988 (now out of print).

[7] L M Edwards, VE7BQH, 'Polarity', *2 Meter EME Bulletin*, May 25 1988 (now out of print).

[8] N Fitch, G3FPK, 'VHF/UHF News', *RadCom*, May 1991, pp 19-20

[9] D R Blaschke, W5UN, 9102 Kings Drive, Manvel, Texas 77578, USA.

[10] B B Cavender, W4ZD, PO Box 1083, Lake Placid, Florida 33852, USA.

[11] J M Carter, K0IFL, PO Box 554, Union, Missouri 63084, USA.

[12] M H Turner, G4PCS, 35 Culverhouse Road, Luton, Beds LU3 1PY.

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